RP 601 Wind Energy Power Plant Collector System Maintenance

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

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Purpose and Scope

The scope of “Wind Energy Power Plant Collector System Maintenance” addresses maintenance of a wind farm “balance of plant” collector system. The scope of this document includes electrical collection system components which are recommended for periodic testing or maintenance. The electrical collection system includes systems starting from the exit of the substation and ending at the turbine connection terminals. This document is not intended to be an all-inclusive how-to manual, but to provide general guidance to sound maintenance practices and references to applicable industry standards.

Introduction

Electrical power equipment and systems testing should be performed as specified by manufacturer’s standards from organizations such as IEEE, IEC, ICEA or NFPA 70B. A summary of some of the applicable standards can be found in NETA standards. In most cases, the testing organization should be an independent, third party entity which can function as an unbiased testing authority and is professionally independent of the manufacturers, suppliers, and installers of equipment or systems being evaluated. The organization and its technicians should be regularly engaged in the testing of electrical equipment devices, installations, and systems. An example of one such organization which has an accreditation program is the InterNational Electrical Testing Association (NETA).

Introduction
(continued)

The testing organization should submit appropriate documentation to demonstrate that it satisfactorily complies with these requirements. The testing organization should provide the following:

- All field technical services, tooling, equipment, instrumentation, and technical supervision to perform such tests and inspections
- Specific power requirements for test equipment
- Notification to the owner's representative prior to commencement of any testing
- A timely notification of any system, material, or workmanship that is found deficient based on the results of the acceptance tests
- A written record of all tests and a final report

Safety and precautions practices should be in accordance with NFPA 70E and other applicable standards including IEEE standards.

Collector System Maintenance

1. Collector Grid Configuration

The influence of the collector system voltage, reactive power flow, and harmonics of the collector system can impact the performance, losses, and life of the equipment. Periodically, it is recommended that the collector system operation be evaluated considering transformer tap settings, voltage set points, reactive power set points, wind turbine generator operational conditions, and overall losses. Harmonic monitoring can be installed to determine conditions where the system can be contributing higher than normal harmonic currents. Overall, the collector system operation can be optimized to minimize I2R losses and evaluated for conditions that may reduce the life of the system.

2. Grounding Grid

The purpose of a ground grid at a wind plant is to ensure the safety of personnel and property. During the commissioning process, the ground path impedance should be minimized, verified, and documented according to ASTM G57-95a and IEEE 81. Measurement of the ground resistance and the potential gradients on the surface of the earth as a result of potential ground currents are necessary for:

- Verifying the adequacy and detecting changes to the grounding system
- Detecting potential hazardous step and touch voltages
- Measuring ground potential rise (GPR) to determine adequacy for protection and communication circuits

2. Grounding Grid
(continued)

Ground grid documentation should be readily available. If changes or repairs to the power system are made, operators should consider testing the associated ground grid to ensure that the alterations have not impacted its effectiveness. Frequent and/or extensive damage to turbine blades or other turbine equipment from lightning damage may indicate a potential issue with the grounding grid system.

3. Circuit Breakers and Switchgear

The power circuit breakers used with the pad mount transformers are used to protect the low voltage (LV) power cable and the equipment within the base of the wind turbine generator. These circuit breakers are typically between 400-2000 volts. The project preventative maintenance program should include these basic items to properly sustain the project. The following list of components should be inspected:

- Thermal Imaging: Verify all terminal connections under high level of generation.
- Housing/Frame: Verify the integrity of the breaker housing.
- Operating Mechanism: Check the physical operation by opening and closing the contacts.
- Trip Unit: Verify the trip unit settings with manufacture testing techniques.
- Terminals: Verify the line and load terminals for obvious visual degradation. Check the torque of the cable and bus terminations.

3.1. Inspection and Testing Frequencies

Switchgear circuit breakers and cubicles should be mechanically inspected and electrically tested at the following intervals or events, and/or following manufacturers recommendations:

- Periodically, at two to three year intervals
- Before placing new or modified breakers into service
- Before energizing breakers that have been out-of-service for over 12 months
- After an interruption of electrical short circuits other than a ground fault in a resistance grounded system
- After 1,000 close-open operations (or fewer, depending on manufacturer's recommendations) following the last inspection

3.2. Cubicle Inspection

During the cubicle inspection process, the following items should be completed:

- Examine the bottom of the cubicle for parts that may have fallen from the breaker. The bottom of each cubicle should be maintained clean and free of any foreign objects to facilitate the detection of fallen parts.
- Verify that the mechanical safety interlocks and stops are intact.
- Check that the cubicle heaters, where applicable, are functioning properly.
- Verify that the rack-in mechanism is aligned correctly.
- Lubricate racking mechanism (jacking screws and bearings) according to station experience or manufacturers recommendations. Check brush length of associated motor when applicable.
- Perform an overall inspection looking for loose wiring or components and anomalies. Complete repairs as required.
- Verify that the shutter mechanism functions properly.
- The primary disconnects should be inspected for signs of over-heating, cracked insulation, cleanliness, and misalignment.

NOTE: Normally, the bus side will be energized; hence, the proper safety measures must be followed.

When the foregoing inspection process is satisfactory to the participating electrician, an adhesive label should be attached to the front of the breaker that indicates the date of inspection and the name of the responsible person.

4. Pad Mount and Grounding Transformers

The pad mount and grounding transformer are typically tested over multiple stages during the commissioning process. The first phase is within the transformer manufacturer's facility prior to shipment. Generally, a prototype is constructed and rigorous acceptance testing is performed on the prototype unit to ensure operating compliance. Tests will vary depending on the manufacturer and specifications from the engineer (based on IEEE/ANSI guidelines). Successive tests are performed on the production units depending on the specifications.

4.1. Electrical Tests

Upon arriving at the site, the transformers are inspected for physical damage. After inspection, the transformers are transported to their final resting place. Prior to connecting any external cable including the MV cables, secondary cables, and ground grid, the transformer should be tested. The recommended tests typically consist of the following:

4.1.1. Transformer Turns Ratio Test (TTR) On All Transformer Tap Positions, If Taps Are Present

The TTR is performed to ensure that the turns ratio of the transformer is correct by verifying that none of the transformer windings are shorted. Generally, values should not exceed 0.5% as compared to the calculated value or the adjacent coils.

4.1.2. Winding Resistance Test (WTR)

- Primary winding to ground
- Primary winding to secondary winding
- Secondary winding to ground

4.1.3. Insulation Resistance Test

The insulation resistance test is important for determining the condition of the transformer insulation. Resistance measurements are made between each set of windings and ground, recording the readings at 30 seconds, 1 minute, and every minute afterwards for 10 minutes. The dielectric absorption rate (DAR) is the ratio of the 60 second resistance value to the 30 second resistance value. DAR readings below 1.25 indicate cause for investigation or repair of the transformer. The polarization index (PI) is the ratio of the 10 minute resistance value to the 1 minute resistance value. A PI value of less than 1 indicates possible deterioration and that the transformer is in need of repair.

4.1.4. Thermal Imagining

For oil filled transformers, use a thermal imager to look at medium and low voltage external bushings, connections, cool fins, and the surfaces of critical transformers.

4.2. Non-electrical Testing

4.2.1. Dissolved Gas Analysis for Transformer Oil

The identity of gases generated in a transformer is useful information in a preventative maintenance program. Gases are created when the insulating mineral oil is subjected to any of the following electrical conditions: corona discharge, overheating, or arcing. The gases result from the breakdown of mineral oil and conductor insulation materials. If gassing is extensive, the upper gas space may contain a lower explosive limit (LEL). Following are gases commonly found in a mineral oil DGA analysis:

Table A

Generated Gas	PPM in Oil (DGA) That Results in Gas Space LEL
Hydrogen (H_2)	2,232 ppm
Carbon Monoxide (CO)	16,625 ppm
Methane (CH_4)	23,214 ppm
Ethane (C_2H_6)	77,700 ppm
Ethylene (C_2H_4)	54,560 ppm
Acetylene (C_2H_2)	30,500 ppm
Carbon Dioxide (CO_2)	N/A

NOTE: N_2 and O_2 are also present in the oil, but are the result of tank air leaks and the oil’s exposure to atmosphere.

To be a potential explosion hazard:

- The combustible gas concentration in the gas space must exceed the lower explosive limit.
- O_2 must be present in the gas space in sufficient concentration.
- An ignition source must be introduced.

4.3. Normal Operations

Routine transformer operations, even if greater than LEL percentage, do not present a personnel hazard. The following evolutions can be safely performed on a transformer with a combustible gas concentration above LEL.

- Oil sampling
- 34 kV disconnect switching operations
- Thermography and internal cabinet inspections
- Voltage measurements
- Medium voltage (MV) & LV elbow and cable terminating
- Insulation resistance testing of windings
- Bayonet fuse replacement/inspection
- Crane and rigging of pad mount transformer (PMT) for movement

4.4. Purge Guideline

The following procedure is applicable if a transformer's upper gas space will be opened or exposed for maintenance or inspection. If hot work is to be performed in any transformer compartment or on transformer components, a purge procedure must be completed. GSUs with an expansion tank (vice N2 blanket) will not have a gas space in the main tank, but could have accumulated gases in the expansion tank. Precautions should be observed if performing work on the expansion tank.

SAFETY NOTE: Explosive gases purged from a transformer gas space may be ignited if they settle or collect in a closed cabinet or stagnant compartment. Keep access doors open and ensure adequate ventilation.

SAFETY NOTE: In addition to the explosion hazard, personnel need to ensure that they recognize the dangers of introducing large amounts of N_2 for purging into a closed or ventilation limited space. Take precautions to maintain a supply of fresh air where personnel are working.

Transformer should be Locked Out-Tagged Out. Grounding may be required depending on system isolation and conditions. Always assume a transformer's upper gas space has a potentially explosive atmosphere that must be diluted and purged. Past DGA oil samples may not exhibit gas-in-oil concentrations high enough to create an LEL, but even a recent DGA sample does not assure that gassing has not occurred in the recent past.

4.4. Purge Guideline
(continued)

NOTE: It is assumed that personnel are using a 4 gas monitor capable of O_2 and LEL measurements, for example a Honeywell Impact Pro Multi-gas Monitor. Check your gas monitor manual to verify samples and that it responds to a variety of combustible gases, including H_2, when developing an LEL percentage.

Smoking, vehicle exhaust, open flame, welding, brazing, etc. in the vicinity of the open gas space is prohibited.

Select two appropriate ports with direct access to the transformer gas space, such as the gas pressure gauge, relief valve fitting, N_2 blanket fitting, gas fill port, access plate, etc. The purge will inject low pressure N_2 into the gas space while venting out the existing gases, thus diluting LEL concentration. Never use a port or access point that is below the transformer oil level, such as the drain valve, top oil temp gauge, or level gauge.

If N_2 purging through a port is impractical, a gas space access plate may be loosened and wedged open to allow free air venting. Check gases released from the tank. Ensure no open flame or ignition source is present until LEL is less than 5%.

Check the transformer nameplate for maximum tank internal pressure, usually 7-10 psi, to avoid damaging the main tank or fins.

Attach a nitrogen gas bottle to one fitting and purge nitrogen into the gas space at low pressure. Verify gas flow into and exiting the transformer. Do not pressurize the tank since most can handle no more than 7-10 psi. If you don't feel gas escaping, STOP.

Monitor the gases escaping the upper gas space. Purge until LEL is less than 5% and decreasing. Stop the purge and let the tank sit for 15 minutes to allow undisturbed gas pockets to re-mix with the N_2 in the upper gas space. Re-initiate the N_2 purge as above. Repeat as necessary until upper gas space is purged of explosive gases and safe to access.

Carefully expose or open the upper gas space to perform hot work. Every couple of hours, if the gas space has not been completely open and ventilated, re-purge to ensure gases-in-oil have not been re-released into the space. Ensure adequate ventilation of fresh air to the work area and cabinet interior.

4.4. Purge Guideline
(continued)

Standard chemical properties for oil include:

- Dielectric strength
- Interfacial tension
- Power factor at 25°C
- Neutralization number
- Water content
- Specific gravity
- Dissolved gas analysis
- PCB

Check list for visual inspection of all components and operation of gauges and controls.

NOTE: It is important to note and record the above results based on the serial number of the transformer, which is typical practice for any third party testing agency. Care should be taken to ensure that accurate readings are obtained and that the results are evaluated by a qualified individual to determine if there are any potential material issues. In the event that the transformer is moved to a different location, it is recommended the above procedure is repeated prior to energization to ensure that damage has not occurred during transport.

4.5. Operational Maintenance

Records of the above commissioning tests should be obtained and used as a baseline. In the case of a transformer failure, these tests should be repeated and documented. To ensure that the performance of the pad mount transformer and grounding transformers continue to meet expectations, visual and infrared camera inspections are recommend on a yearly basis. Oil sampling is recommended on one third of the transformers on a yearly basis. In general, transformers closer to the substation are more critical since disruptions to the collector system closer to the substation put the availability of the wind site at a higher risk.

5. Pad Mount Transformer Foundation

The pad mount transformer are installed on concrete slabs or many time on prefabricated fiberglass or fiber-crete box pads. These foundations should be visually inspected for cracking and periodically sealed to mitigate rodent and water access. The sealant should be periodically inspected to minimize water ingress.

6. Secondary Cable Systems

6.1. In many cases, secondary cables are utilized between the turbine controller and the collection system pad mount transformer. The secondary cable insulation rating will range from 600 V to 2000 V depending on the cable design and the wind turbine generator (WTG) type. Typical installations will require multiple conductors per phase. Conductors should be properly labeled with phasing tape or colored cable jackets. After installation and prior to termination to the transformer and controller, a DC insulation resistance test ("megger") is typically performed. The test voltage is dependent on the insulation value but is usually in the range of 500 V to 2,500 V. The intent of the installation tests are to:

- Ensure that the insulation was not shorted during the installation process. A low voltage insulation resistance measurement of less than 100 Megohm may indicate a problem.
- Verify the cable phasing from one end to the other.

Generally, secondary cable systems are not re-tested as a maintenance practice unless there is reason to suspect a problem. An annual infrared inspection of the terminals is recommended especially on cables deemed critical.

7. Fiber Optic Cable Systems

Upon installation and termination of the fiber optic cables from each WTG, tests are performed to ensure the quality of the fiber optic cable and terminations. Typically one of the following two tests are performed:

- Attenuation (dB) loss testing
- Optical time domain reflectometer (OTDR) testing

Since the network is constantly used for data transmission, it is, in effect, constantly monitored. If there is a network problem, one of the tests above can generally help diagnose the problem. Other than a visual inspection of the connections, periodic maintenance is generally not necessary.

8. Overhead Cable Systems

9. Medium Voltage Cable Systems

Medium voltage cable systems can be found as a part of the collector system and tower cables. During commissioning, field tests range from legacy methods, such as insulation resistance and withstand methods, which are only effective at detecting gross shorts (cable system failures), to sophisticated, predictive partial discharge (PD) tests which detect and locate gross and subtle insulation defects and provide a baseline for future use.

9. Medium Voltage Cable Systems
(continued)

The standardized electrical test requirement at the factory for all completed solid dielectric shielded cable insulation system components, including the cable, joints, and terminations, is a partial discharge test performed during a 50 Hz or 60 Hz over voltage. Ideally a partial discharge test comparable with the factory test can be repeated on installed cable systems to assure that they still meet these requirements. If this type of test is not available or deemed impractical for a specific application, a list of alternative tests can be found in the IEEE 400 guide document.

Ideally, during commissioning the following steps are completed on the cable system and a baseline is established:

- Visual inspection for physical damage, such as bends at less-than-minimum bending radius, phase identification, fireproofing, proper shield grounding, cable supports and termination connections, required size and rating per design drawings, and proper separation of power, control, instrumentation, and emergency circuits.
- Conductor phasing test
- Resistance of neutral wires and tapes and conductor resistance/ continuity
- Off-line 50 Hz or 60 Hz PD test on each individual span of cable from termination to termination point. This test can provide a profile of the cable system which is comparable to factory standards listed below.
- DC Insulation resistance test (“megger test”) or very low frequency AC test, at the operation voltage or less, on the entire cable system. This test is not intended to detect defects which may fail in the near future but, rather, to detect pre-existing shorts.
- Infrared test of the accessories (terminations and accessible splices) under high current condition.

Table B: Cable System Insulation Test Standards.

Cable Component	Thresholds
IEEE 48 Terminations	No PD >5pC up to 1.5Uo
IEEE 404 Joints	No PD >5pC up to 1.5Uo
IEEE 386 Separable Connectors	No PD >3pC up to 1.3Uo
ICEA S-94-649 MV Cable	No PD >5pC up to 2Uo*

*Actually 200 V/mil in factory. Field tests are performed to a maximum voltage value equal to the level of system over voltage protection which is typically 2 times the operating voltage for 35 kV systems (line to ground, 1.0Uo).

9.1. After a Failure

A DC insulation resistance test at operating voltage or less, i.e. 10 kV or 20 kV for a 35 kV system, is recommended after any failure event to confirm the phase of the fault and to confirm that there is not a second fault before re-energizing. Arc reflection fault location technology should be used with a minimum of pulses to determine the location of the fault. To confirm dielectric integrity of the system after repair, an off-line 50 Hz or 60 Hz PD test is recommended.

9.2. Cable Fault Location Equipment/Thumpers

Fault locating methods use fault indicator ("thumpers"), radars, acoustic detectors, or combinations of this equipment. Research indicates that subjecting cable systems to unnecessary surges reduces their remaining life. The industry has developed less evasive fault locating methods that reduce the stress on cable insulation systems. The general approach is to reduce the amount of thumping necessary to locate a fault while simultaneously reducing the voltages required to perform the task.

9.3. Periodic Testing

Comparative infrared testing is recommended annually to check the condition of the mechanical connection of cable system joints and terminations. Off-line 50 Hz or 60Hz PD testing is recommended every 5 years. In many cases operators will focus testing efforts on systems that are most critical (nearest the substation), that have components with a history of failure, or that have components with marginal performance during past tests.

10. Surge Arrestors

Surge arrestors provide over voltage protection for dielectric components. During an over voltage event the surge arrester will become more conductive and shunt the excessive voltage to ground. Arrestors can fail during excessive over voltages or if there is moisture ingress. If arrestors are not functioning properly, the components they are designed to protect will likely fail prematurely.

10. Surge Arrestors
(continued)

During commissioning, surge arrestors on the high and low side transformer and the beginning, mid-point, and end of cable systems typically have the following tests and inspections performed:

- Verify that "station class" arrestors are installed at MV and HV underground to overhead structures.
- Verify nameplate ratings against owner's specification.
- Insulation resistance test and/or power factor testing should result in similar test results between similar units.
- Test for low impedance path to ground grid with no sharp turns.
- Check the lead length to assure that is it not longer than the manufacturer's requirement. Long lead lengths cause the device to malfunction. In the absence of the manufacturer's requirements, lead lengths should be maintained less than 18 inches for MV systems and 3 feet for HV systems.

Dead-front (T-body type) surge arresters are typically installed at the last WTG in each turbine string for the purpose of protecting collector system equipment from transient overvoltage stresses. To ensure proper functioning, the surge arresters should be physically and infrared inspected after major events and during periodic inspections.

Surge arrestors are also used at cable system cross-bond points. These arrestors should be inspected and tested according to the manufacturers recommendations. Lead length should be less than 3 feet. Confirm proper lead length and arrestor sizing with your joint manufacturer.

Maintenance of arrestors is recommended. Arrestors should be visually inspected annually, and infrared inspection should be performed every 2 years or after system failures or per the manufacturer's recommendation.

11. Arc Flash

The arc flash hazard analysis and safety program should be implemented at the early stages of a project. This safety program should be periodically updated, while the arc flash hazard analysis should be revaluated at a minimum of every 5 years or if the system or connecting electric grid has changed. A proper safety program with equipment should be applied per the NFPA 70E and all federal and local codes.